Spatio-Temporal Characterization of Bio-Acoustic Scatterers in Complex Media

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LONG TERM GOALS

To develop a methodology for extracting the relevant spatial and temporal scales of bio-acoustic scatterers based on multi bi-static long-range measurements in shallow water waveguides.

OBJECTIVE

Characterization of biologically-induced ocean reverberation features is key to effectively parametrize acoustic models and thus ultimately improve the detection performance of long-range SONAR systems. Ocean reverberation signals measured in shallow water can be thought to result from the combined effect of both two-way multipath acoustic propagation and the intrinsic scattering function of compact (e.g. fish aggregates or submerged target) or extended (e.g. rough seabed) acoustic inhomogeneities. In particular, multipath effects in shallow water effectively yield multiple probing of the complex scattering function of fish aggregates or marine mammals. This complexity of the acoustic propagation and biological scattering prevents the use of conventional remote sensing techniques for mid-frequency long-range SONAR systems.

The mid-frequencies regime (1kHz-10kHz) appear as an attractive trade-off between the achievable spatial resolution and operating range of the SONAR applications. In this mid-frequency range, bottom reverberation will consist of scattering from the interface, within the sediment volume, and any layers within the sediment volume. Furthermore, acoustic inhomogeneities distributed in the volume of the water column (e.g. internal waves, marine biota) will lead to volume reverberation. Additionally, temporal variability of the ocean environment (e.g. due to motion of the rough ocean surface or the marine biota) will also cause fluctuations of ocean reverberation and hence affect the stability of mid-frequency SONAR measurements. Such oceanic variability can increases the uncertainty of SONAR prediction modeling tools (up to tenths of dB) as well as potentially increases false-alarm rate of mid-frequency SONAR systems. Hence, it is thus critical to characterize the relevant *spatial and temporal scales* of the various scattered fields (e.g. rough seafloor vs. fish aggregates) generating ocean reverberation to effectively parametrize acoustic models and improve the detection performance of long-range SONAR systems.

The main objective of this research effort is to develop a framework for extracting physical parameters of moving bio-acoustic scatterers (e.g. size, trajectory, frequency response) from long-range SONAR measurements in shallow water waveguides.

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APPROACH

Assessing the biologically-induced acoustic uncertainty in shallow water involves theoretical and experimental efforts to first better understand- and ultimately model- the physics of propagation and scattering in complex media. When compared to traditional measurements of marine biota with conventional close-range fisheries SONAR (e.g. for fish school sizing), long-range measurements of the same marine biota in sallow water waveguides have unique features and challenges associated due to the coupling of multipath acoustic propagation and complex target scattering functions. Indeed, multipath effects effectively yield multiple probing of the scattering function of the fish aggregates or marine mammals (see Fig. 1), thus leading to complex measurements for long-range SONAR systems. From a remote sensing perspective, this complex coupling of multipath acoustic propagation and bio-acoustic scattering can be analyzed from two complementary approaches:

- On one hand, multipath effects are a nuisance which should be removed from deterministic measurements if one wants to obtain a better estimate of the intrinsic or free space scattering function (traditionally measured at closed range) of specific fish aggregates or marine mammals Thus, it becomes useful to develop specific blind deconvolution technique to mitigate multipath effects from long-range measurement of biologically-induced scattering.

- On the other hand, multipath effects can potentially be advantageous as they statistically provide multiple view points of the same bio-acoustic scatterers. Consequently, information of the spatial and temporal scales is naturally embedded in long-range reverberation measurements. Thus we will investigate the spatial and temporal coherence of long-range ocean reverberation measurements as a means to extract statistically the relevant spatial and temporal scales of bio-acoustic scatterers (e.g. cross section, mean free path, frequency response).

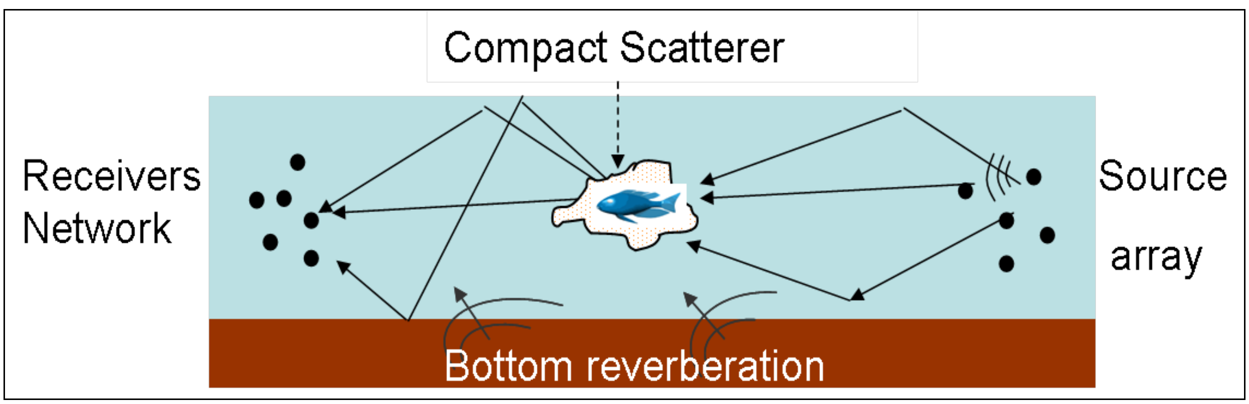

Figure 1: Schematic of a Multi-bistatic SONAR system operating in a shallow water waveguide for long-range detection (in forward scattering geometry here). Source and receiver systems can have various spatial configurations depending on the practical SONAR system implementation. Multi-bistatic measurements of ocean reverberation result from the combined effect of both (1) the intrinsic scattering function of compact (e.g. fish aggregates or submerged target) or extended (e.g. rough seabed) scatterers and (2) two-way multipath acoustic propagation (along the source- scatterer-receiver paths).

WORK IN PROGRESS

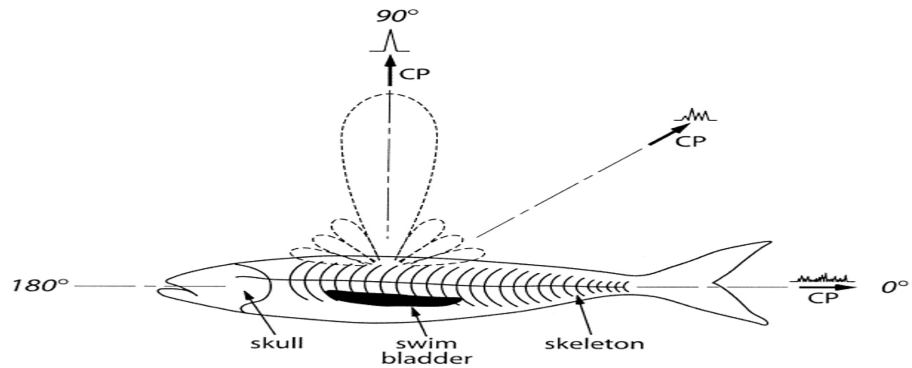

Figure 2: A schematic illustration of a compressed echo or pulse (CP) as a function of backscatter direction for a fish specimen. Note the strong spatial directionality of the fish's scattering function due to the anatomical structure of the fish [Reproduced from Stanton et al., JASA, 2003]

In the first year of this research effort, we are developing a numerical model to predict the influence of the spatial beampattern and frequency features of the target scattering function on the recorded scattered fields by diverse source-receiver network configuration (see Fig. 1). We will use this model to generate the relevant statistics and realizations for our selected configurations.

The linearized Born approximation formulation provides the starting point towards a simple parametrization of the mid-frequency multistatic sensing of the scattered field in a waveguide. Furthermore, bio-acoustic scattering is known to strongly depend upon the orientation of the fish aggregates and probing acoustic frequency, thus knowledge of its spatial and frequency distribution (e.g. beampattern) will help parametrizing the relevant spatial and temporal scales of bio-acoustic scattering [*Stanton et al., 2003*] (see Fig. 2). Additionally a straightforward and computationally efficient method of computing the Green's function in a shallow water waveguide is the method of images or ray propagation models. Furthermore, long-range SONAR measurements imply that sources and receivers are located in the far-field of the fish aggregates or marine mammals. Hence, these acoustic propagation components can in turn be easily coupled to the plane wave scattering function of the target (or T matrix) using a simple parametrization in term of incident and scattered angles (or spectral wavenumbers more generally) [Ingenito, JASA, 1980, Lucifredi and Schmidt, JASA, 2006]. In this case, the various incident (scattered) multi-paths propagating to (away from) the target can be approximated by a discrete set of plane waves propagating at various angles (see Fig. 3).

We are implementing two approaches to compute the plane wave scattering function for a fish school modeled as an aggregated of ellipsoid-shaped scatterers (representative of the fish swimbladders shape and physical properties). The first approach involves a semi-analytical model for an perfect ellipsoid shape randomly distributed in a given volume. The second approach uses COMSOL Multiphysics-a commercial finite element model- to directly compute the plane wave scattering function of individual fish or fish aggregates using more realistic shape of the fish anatomy and physical properties (e.g. see Fig. 2).

Finally, we are extended our acoustic scattering formulation to account for the case of moving scatterers using the multi-modal (or multi-wavenumber) Doppler effects characteristics of ocean waveguides [Kuperman and Schmidt, JASA, 2004;Lai and Makris , 2001].

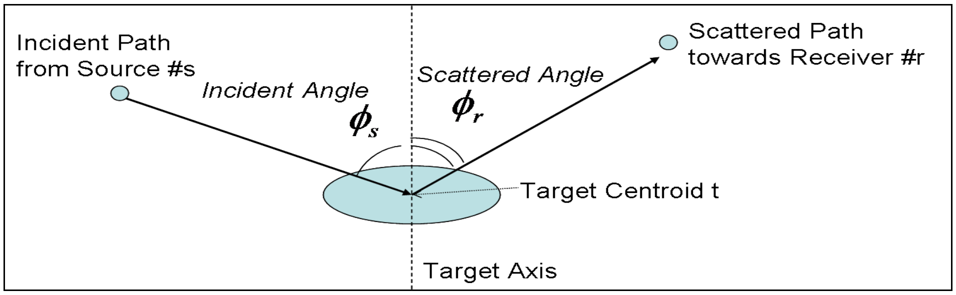

Figure 3: Angular parametrization for the far-field scattering from an axisymetric target

IMPACT

It is conjectured that the results of this study could potentially improve the remote detection, classification and localization of marine bioata using long-range mid-frequency SONAR systems, as well as reducing the uncertainty of SONAR prediction modeling tools due to marine biota.